TECHNICAL REPORT 9002

THE MILITARY EFFICACY OF INDIVIDUAL WATER PURIFICATION FILTERS

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Tests were conducted to determine the effectiveness of Katadyn™ Pocket Filters (KPF) to remove enteric bacteria (Klebsiella terrigena), protozoan cysts (Cryptosporidium parvum), and cyst simulants. Studies used the U.S. Environmental Protection Agency's "Guide Standard and Protocol for Testing Microbiological Purifiers" for guidance. Results showed that cysts were effectively removed by the filters over a typical 100 gallon use life of the ceramic filter candles used in the KPF. Bacterial removals were shown to also meet the criteria when improvements to end seal gaskets of the ceramic filters were made. Silver leaching tests indicated that EPA criteria were not always met; however, this leaching did not prevent growth of opportunistic bacteria on the product water side of the filters. A health hazard assessment was performed on the KPF.

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SUMMARY

The Katadyn Pocket Filter (KPF) is designed to treat fresh water to produce drinking water free of pathogenic protozoa and bacteria, even from water sources heavily contaminated with micro-organisms. This filter has potential as a candidate device for the military to provide the individual soldier with the capability to provide personal drinking water treatment when water cannot be resupplied from military bulk water assets. Studies were conducted at the U.S. Army Biomedical Research and Development Laboratory (USABRDL) to evaluate the effectiveness of the KPF to meet U.S. Environmental Protection Agency (USEPA) criteria and to determine the effective use-life of KPF for further consideration of use by the Army and Marine Corps. The studies concluded that the improved KPF was able to provide effective treatment of challenge bacteria as well as protozoan cysts and cyst simulant, meeting the USEPA criteria, and also demonstrated an effective use-life of over 100 gallons. The principal health hazards identified in this report are: pathogen contamination of hands upon cleaning the ceramic candle; potential ceramic candle filter failure upon excessive use of force to operate the unit; and silver leaching in excess of USEPA drinking water criteria. The risk assessments and recommendations of major concerns are addressed. Proper instructions must be given to personnel on use of the KPF and its potential hazards. In order to provide total microbiological purity, disinfectants such as military issue globaline tablets must be added in the prescribed manner to the filtered water before consumption to eliminate enteric virus hazards.

PREFACE

The authors would like to extend their appreciation to Drs. W. Dickinson Burrows and Howard Bausum of the U.S. Army Biomedical Research and Development Laboratory for their help in editing this manuscript. Also, thanks is given to Mr. Ted Kuepper, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, for his review of the technical data and interest in this study.

INTRODUCTION

The U.S. Army and U.S. Marine Corps have for many years relied on microbiological water purification by addition of 1-2 iodine tablets (globaline) to insure the safety of pickup water for combat units not able to obtain military bulk treated water. While iodine tablets are very effective for disinfection of waterborne bacterial pathogens such as salmonella, shigella, cholera, coliforms, etc., these tablets are not nearly as effective in treating protozoan cysts and viruses, especially at low water temperatures and low pH. Also, iodine tablets, when used in their current configuration of two tablets per quart canteen, produce adverse taste and odor characteristics which hinder proper hydration due to avoidance of the disinfected water. These bad organoleptic characteristics cause soldiers to find other possibly nondisinfected sources, or to add substances to mask the flavor, which may tie up the iodine thus reducing its effectiveness. During the late 1980's the Services identified requirements to improve the soldiers' "pickup" water microbiological treatment capability. One approach was to utilize purification filters which will exclude micro-organisms that exceed the size of the filter pores. This report describes one type of hand-held water filter that appears to have some characteristics of interest for individual soldier water purification.

The hand-held Katadyn Pocket Filter (KPF) (Figure 1) is a small (250 mm long and 50 mm diameter) individual drinking water treatment unit weighing 23 ounces. It has a 28-inch suction hose to reach the water source and an integral handpump to force water through the unit. The KPF unit is stored within a small, water-resistant, zippered bag, and is accompanied by a small scrub brush, a feeler gauge (to determine when the ceramic filter material is worn out), and instructions on its use.[1] The KPF is a Swiss-made commercial item that is distributed as a nondevelopmental item (NDI) in the U.S. by Katadyn USA Inc., Scottsdale, AZ. The KPF is manufactured by Katadyn Products Inc., CH-8304 Wallisellen, Switzerland. Currently there is no standard item in the Army that this unit is replacing. Without the addition of a water disinfection procedure, the KPF will not meet previous or planned Army Letter Requirements as stated for the development of the Individual/Small Unit Fresh Water Purification Device (FWPD), since it has been shown to not effectively filter out certain enteroviruses and is not effective in removing chemical threat agents or toxins.[2] A safety assessment report on the KPF was conducted by the Army in 1989 in which no safety hazards were reported during the use of this item.[3]

The KPF is intended for removing turbidity, pathogenic protozoan cysts (such as Giardia lamblia and Cryptosporidium parvum) and pathogenic bacteria (such as enteric bacteria, Yersinia enterocolytica, Campylobacter jejuni, non-tubercular

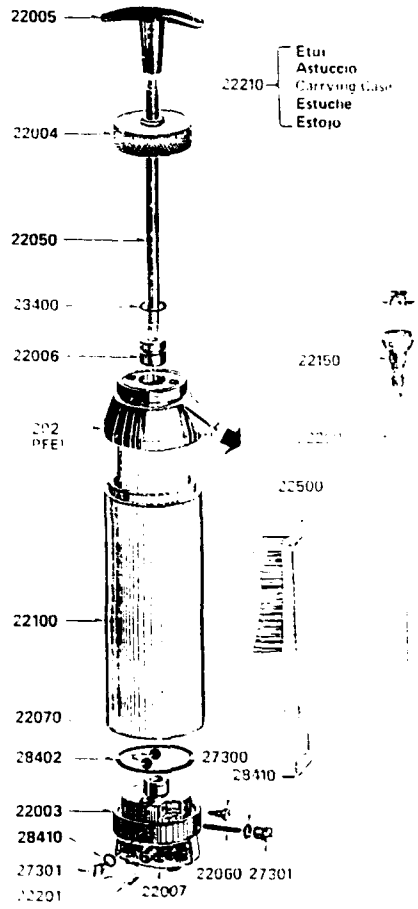

Figure 1. Katadyn Pocket Filter

mycobacteria, Legionella spp., and Pseudomonas spp., from fresh **water sources. The KPF removes these pathogens by filtration** through the 0.2 μm ceramic filter candle using a hand-pump piston mechanism integral to the unit. No claim is made for virus removal. The device is designed to provide about 700 ml of product water per minute (1 liter in <90 seconds) and is claimed to have the capacity to produce over 400 gallons of water before the ceramic filter candle needs replacement. Silver, as silver oxide, a bacteriostatic agent, is impregnated in the ceramic filter matrix to prevent microbial grow-through or colonization of the filter. To the knowledge of the project investigators, the KPF has not been tested to demonstrate that it is capable of removing high levels of human enteric viruses (such as infectious hepatitis virus, Norwalk virus, rotaviruses and enteroviruses) from water. As a preliminary step to this study, the U.S. Marine Corps (through the U.S. Naval Civil Engineering Laboratory) conducted a market survey which evaluated nine different individual water purifiers.[4] As a result of the microbiological

testing performed in the present study, the marines are currently utilizing the KPF for individual water production in support of field operations, where it is used in conjunction with disinfection by addition of two globaline tablets for a contact time of 30 minutes (because viruses are not removed sufficiently from field waters).[5]

During this study an Army prototype water purification filter produced for the Natick Army Research, Development and Engineering Center was also evaluated for its ability to produce cyst and bacteria-free water (Figure 2). This unit was also a hand-held device which contained a disposable charcoal filter encased in a plastic housing, which was attached to a separate pump assembly and associated inlet/outlet hose. This unit was devised so that the rubber hose connecting the pump to the filter would disengage when the pressure on the filter increased to an inacceptable level due to clogging. (The charcoal filter was to be replaced when clogging occurred.)

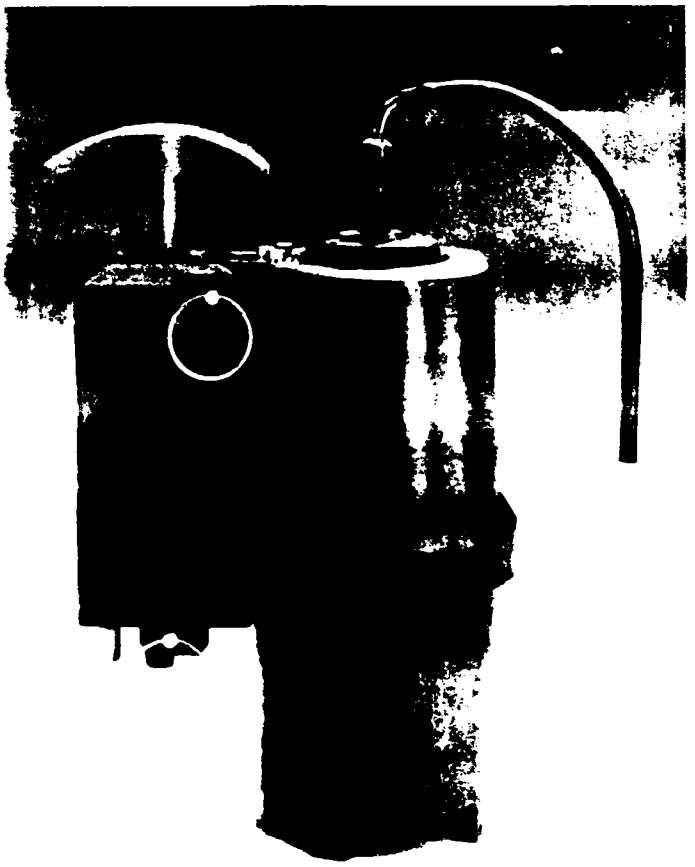

Figure 2. Army prototype purification filter

Microbiological treatment capabilities of the KPF were evaluated by the U.S. Army Biomedical Research and Development Laboratory utilizing the U.S. Environmental Protection Agency's (USEPA) interim "Guide Standard and Protocol for Testing Microbiological Water Purifiers" for guidance.

METHODS

1. SHORT-TERM EFFICACY TESTS USING USEPA GUIDE STANDARD AND PROTOCOL FOR TESTING MICROBIOLOGICAL WATER PURIFIERS

a. Microbiological challenges

(1) Bacteria

(a) Stock preparation--Klebsiella terrigena (strain = 33257) was obtained from the American Type Culture Collection (ATCC). Bacterial stocks were prepared from overnight cultures grown at 35°C in nutrient broth with 8% glycerol. The culture was dispensed into tubes in one ml volumes and frozen at -70°C. These frozen bacterial cells were then used as inoculum to prepare the broth cultures used in the challenge studies.

(b) Bacteriological preparation for challenge testing--A preliminary experiment was conducted to establish the dilution of bacterial cells needed to achieve a seed concentration of 1.0 X 10^8/ml. Klebsiella terrigena bacteria were grown in nutrient broth for 24 hours in a 35°C shaking water bath to obtain a stationary phase culture. The bacterial cells were pelleted by centrifugation at 13,000 X g, washed three times in pH 7.0 sterile phosphate buffered saline (PBS), and filtered through a sterile Whatman # 2 filter paper to remove cell clumps. Dilutions of 1:10, 1:100 and 1:1000 of the filtered suspension were read in a Klett-Summerson photoelectric colorimeter. Each of these diluted suspensions was further diluted in PBS and assayed for colony forming units (CFU) by filtration of 1.0 ml through each of three 47 mm Millipore filters (Type HAWG, 0.45 µm pore size). Each filter was then placed on a 47 mm pad which contained 2.0 ml of m-Endo broth MF (Difco) in a 50 x 9 mm snap-cap petri dish (Falcon 1006). Plates were incubated at 35°C for 24 hours and counted. This experiment was repeated in triplicate. An average of the three showed that a reading of 33 on the colorimeter scale contained =1.0 X 10^8 bacterial CFU/ML.

Klebsiella bacteria cultures were prepared daily for each filtration challenge test. The test bacteria were grown overnight in nutrient broth and collected by centrifugation. The bacterial pellets were then washed three times in sterile PBS, resuspended in PBS, and filtered through a sterile Whatman # 2 filter paper. The test inoculum was prepared from the filtered suspension by further dilutions in PBS until a reading of 33 was

obtained on the Klett-Summerson colorimeter scale. A volume of the final dilution of bacterial suspension was added to the challenge water tanks to contain 1 X 10^8 CFU/liter of test water.

(c) Assay procedures--All water samples collected to determine test unit filtration efficiencies for bacterial removal were diluted in pH 7.0 PBS and assayed in triplicate, in accordance with the "Standard Methods for the Examination of Water and Wastewater" utilizing the membrane filter technique with m-Endo medium.[6] After 24 hours incubation at 35°C, all colonies with a metallic surface sheen were counted.

(2) Cysts/Simulants

(a) Stock preparation--Fresh calf feces (50% in 2.5% potassium dichromate) containing Cryptosporidium parvum oocysts were obtained from the University of Idaho, Dept. of Veterinary Science, Caldwell, ID, and partially purified for the filter challenge studies, using a modified PBS-ether sedimentation method of Waldman, et al.[7] Ten ml volumes of the calf feces suspension were dispensed into 50 ml polypropylene conical centrifuge tubes, and an equal volume of PBS (pH 7.0) containing 0.1% Tween 20 was added. The contents of the tubes were mixed by vortexing, sonicated three times for 5 seconds in an ultrasonic bath, and centrifuged at 750 X g for 10 minutes. The liquid portions were discarded, and the pellets were resuspended in 15 ml PBS-0.1% Tween 20. Five ml of anhydrous ether was added and mixed with the suspension for one minute. The tubes were then centrifuged at 500 X g for 10 minutes. The top three layers (ether, debris plug, and PBS-Tween 20) were removed and discarded. The pelleted cysts were resuspended in 10 ml of PBS containing 0.01% Tween 20 and pooled. The suspension was examined microscopically for Cryptosporidium oocysts, indigenous yeasts, and debris as described below. The oocysts, which were spherical and measured 4.0-4.5 µm in size, were counted in a hemacytometer chamber. The stock suspension generally contained 1.4 X 10^6 oocysts/ml. The partially purified oocyst stock suspension was determined to be free of extraneous coliform bacteria contaminants, by fecal coliform analyses using the membrane filter technique with m-Endo medium. It was also devoid of debris which would interfere with microscopic quantitation. The stock oocyst suspension was stored at 4°C.

Rhodotorula rubra (ATCC # 36053) was selected as a protozoan cyst simulant. The yeast was grown on YM agar (Difco) in 150 mm petri dishes. Each plate was inoculated with 1.0 X 10^5 yeast cells, and the cultures were grown at room temperature for 48 hours. Yeast cells from each plate were collected in 100 ml of sterile deionized distilled (dd) H_2O, pooled, and counted. Yeast cells were determined to remain viable at 4°C for at least 10-14 days; however, fresh challenge stocks were grown weekly and stored at 4°C for use in the studies.

A second cyst simulant, 3.7 μm latex Accubeads® obtained from Fastek (Division of Eastman Kodak Co.), was also used in the studies. The latex beads were diluted in sterile dd H_2O [containing 50 μg/ml of sodium dodecyl sulfate (SDS) to prevent clumping] to a final concentration of 2.0 X 10^7/ml for experiments.

(b) Preparation of microbiological challenge for testing--On each day of testing, cyst and simulant challenges were prepared and quantified. After the Cryptosporidium parvum oocysts were counted in a hemacytometer to verify the morphology and concentration, a volume of the cyst suspension was added to provide approximately 2.0 X 10^6/liter of test water. The Rhodotorula rubra yeast suspension was diluted in dd H_2O (containing 0.01% Tween 20), counted, and added to provide a final concentration of approximately 2.0 X 10^7/liter of test water. Immediately prior to addition of the latex beads to the test water tanks, the bead suspension was sonicated briefly, mixed well to disperse clumps formed during storage, and added to provide a final concentration of 2.0 X 10^7/liter of test water.

(c) Assay procedures--Enumeration of yeasts, beads, and oocysts in test water samples was performed in the following manner: Sample volumes of 100 ml of the challenge water and 1000 ml of the filtered water from the KPF and Army prototype units were collected, sodium thiosulfate neutralized, and processed separately in glass flasks. A final concentration of 0.1% Tween 20 and 1.0% newborn calf serum was added to each sample to prevent adsorption of the test materials to the glass collection flasks. Each sample was then filtered through a 47 mm diameter, 1.0 μm pore size, Nucleopore polycarbonate membrane (Cat. # [illegible] Nucleopore Corp., Pleasanton, CA), followed by a wash of 100 ml of dd H_2O containing 0.1% Tween 20. The filter membrane was transferred to a 60 mm plastic petri dish and washed with 5.0 ml dd H_2O containing 0.01% Tween 20. The wash was collected into a 50 ml polypropylene centrifuge tube. A second 5.0 ml of the wash solution was pipeted over the membrane, and the petri dish was floated on a sonicating water bath for 5 - 10 seconds. This wash material was also collected and pooled with the first wash. Using sterile forceps and scalpel, the filter membrane was cut into eight pieces, placed into a separate 50 ml centrifuge tube, and ten ml wash solution was added. The tube was shaken approximately one minute; then the wash material was collected and pooled with the previous washes. This step was repeated two times. The membrane was given a final ten ml wash with vigorous mixing for one minute. The tube containing all the wash material was centrifuged at 1200 X g for 10 minutes at 4°C. The liquid portion was discarded, leaving a volume of 0.8-1.0 ml to resuspend the pellet. A minimum detection level of 1.0 X 10^3/liter was established for counting the yeasts, beads, and oocysts using hemacytometer counting procedures.

For cyst and cyst simulant quantification, a 200 µl volume of a concentrated yeast-bead-oocyst suspension was pipeted into duplicate four ml polypropylene tubes; and a volume of 100 µl of 2% malachite green stain was added to each tube. After a 30-minute staining period at room temperature, a volume of 100 µl of 1% sulfuric acid was added to each tube just prior to counting. The contents of the tubes were mixed and sonicated briefly to disperse clumps of yeasts and beads. For quantification a coverslip was placed on a hemacytometer, and the chamber was filled with the sample to be counted using a pasteur pipet. The filled chamber was allowed to settle for at least two minutes (beads settle slower than oocysts or yeasts). By this method, oocysts were readily detectable by their morphology and absence of staining; whereas, yeasts were distinguishable by their morphology and the adsorption of green stain. Latex beads appeared as well-defined, color-free, refractory spheres. For each sample tube, one hemacytometer chamber of 5 squares was counted, unless the average of each square contained ≤ 1; then both chambers (10 squares) were counted. Counts of the duplicate sample tubes were averaged. If no yeasts, beads, or oocysts were found in the filtered samples, the assay procedure was repeated using undiluted sample material.

b. Test water characteristics

(1) Preparation

(a) General challenge water--Tapwater was collected in polypropylene tanks from the laboratory water supply. The water was dechlorinated by addition of 10 mg/liter of sodium thiosulfate for at least 30 minutes. After dechlorination, the water pH was 7.7 at an ambient temperature of approximately 20°C and contained approximately 1 Nephelometric turbidity unit (NTU). All general challenge water for filtration studies was dosed with Klebsiella terrigena bacterium (1.0 X 10^8/liter), Rhodotorula rubra yeast (2.0 X 10^7/liter), and the latex bead simulant (2.0 X 10^7/liter). A separate challenge volume, containing all of the above and also Cryptosporidium oocysts (2.0 X 10^6/liter), was prepared in a smaller container during testing of the Katadyn filters. The use of the small separate container of challenge material was necessary to conserve cyst material and to reduce the volume of material that required a more stringent sample decontamination process to disinfect oocysts.

(b) High challenge water--Tapwater was collected in polypropylene tanks from the laboratory water supply, and the challenge water was prepared in accordance with USEPA "Protocol for Testing Microbiological Water Purifiers," (Section 3.3.3, Test Water # 3, Challenge Test Water/Ceramic Candle or Units With or Without Silver Impregnation).[8] The silver leaching test (USEPA Protocol, Section 3.3.5, Test Water #5) was not utilized

in this series of tests, but was completed in a later test (to be described). The specific water characteristics stated in the USEPA Protocol were as follows:

"Free of any chlorine or other disinfectant residual;" - Sodium thiosulfate, 10 mg/liter of test water, was added to the challenge waters to neutralize residual chlorine.

"pH 9.0 $\pm$ 0.2;" - The pH was maintained during runs at 9.0 with addition of 1N KOH.

"Total organic carbon (TOC) not less than 10 mg/liter;" - Humic acids, sodium salt, (Cat. # H1,675-2; Aldrich Chemical Co.) was incorporated at 10 mg/liter.

"Turbidity - not less than 30 NTU;" - Product list PP2E-Standardized Arizona Test Dust Contaminant (Reference SAE J 726 Specification) was obtained from Powder Technology Inc., Burnsville, Minnesota. Particle size distribution was as follows: 12% five microns; 12% ten microns; 14% twenty microns; 23% forty microns; 30% eighty microns; and 9% two hundred microns. A turbidity of 30 NTU was obtained using 125 mg/liter of test dust for the challenge test water, as measured in a Klett-Summerson photoelectric colorimeter with a number 42 blue filter in place.

"Temperature - $4^{o}C \pm 1^{o}C$;" - Test water temperatures were maintained between $4^{o}C$ and $11^{o}C$, except the challenge water which was maintained at $4^{o}C$ during sampling periods.

"Total dissolved solids (TDS) - 1,500 mg/liter $\pm$ 150 mg/liter." - Sea salt (No. S-9883, Sigma Chem. Co.) was added to a concentration of 1500 mg/liter of test water.

c. Testing procedures

(1) Test set up--KPF ceramic candle filters, (serial numbers 74906, 74941 and 74781) were designated as units 1, 2, and 3 respectively, for the laboratory tests. For testing, the KPF filter assemblies were mounted horizontally on a wear-tester machine driven by a 1/3 hp motor (Figure 3). The filters were held securely to a wooden block, and the KPF pump shafts were connected to a cam-operated arm attached to a pulley. The intake hoses of the KPF were connected to the 40-liter test water supply tank (Figure 4), which had a variable-speed electric stirrer attached to keep all water constituents uniformly dispersed and suspended. A sterile rubber tube was also attached to the product water spout of the filters, and the treated water was collected in a clean Nalgene polypropylene tank. Water generally passed through the units at a rate of between 200 to 300 ml per minute using approximately 22 pump strokes per minute. Figure 5 depicts the appearance of general challenge water (beaker 1),

worst case challenge water (beaker 2), and worst case water after filtration (beaker 3). All Katadyn filters were flushed by pumping 500 ml of sterile dd H_2O through the ceramic candle filter at the end of each sample day, except prior to the 48-hour stagnation collections. The units were stored intact to prevent drying of the candle filter.

(2) Test operation

(a) Each KPF candle was tested in succession, with the order reversed every operating day to compensate for any time related changes to simulants or organisms in the challenge containers. The filter units were disassembled; and the ceramic candles were cleaned with the brush provided with the units and rinsed with dd H_2O, only after the 48-hour stagnation sample for general test water; and at the end of days 6, 7, 8, 9, and after the 48-hour stagnation sample for worst case challenge water.

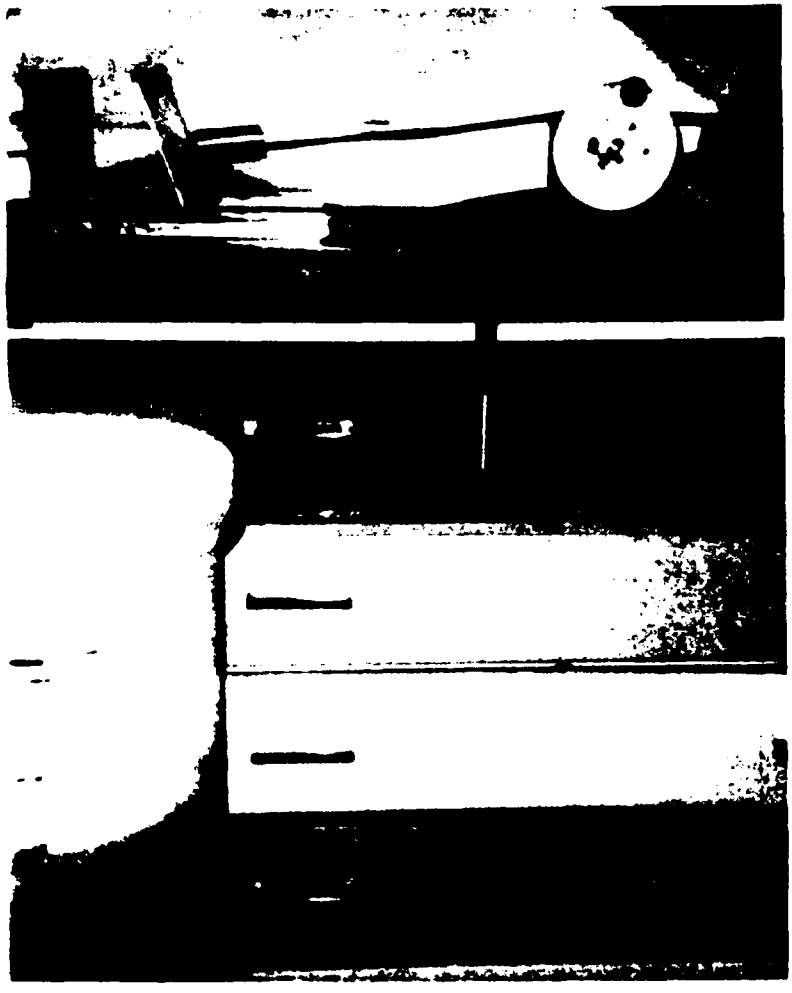

Figure 3. Wear-tester machine

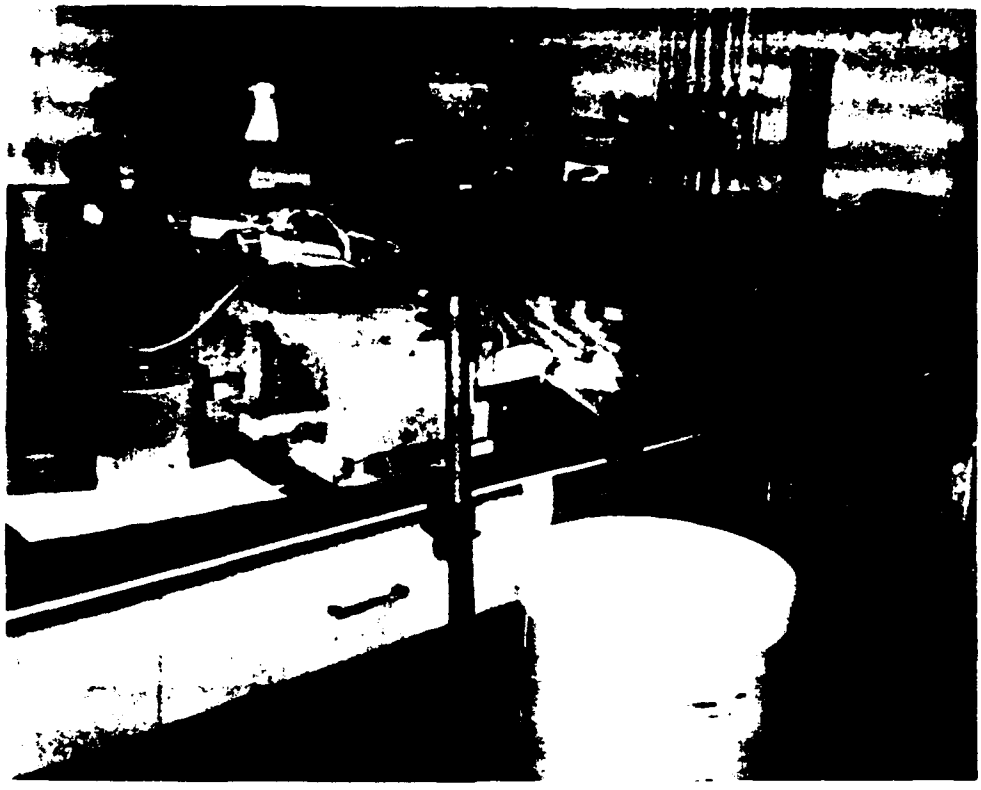

Figure 4. KPF connected to a 40-liter test water supply tank

(b) For the laboratory tests, the Army filter unit was manually operated and run simultaneously with the Katadyn hiker filters using the various test waters. It produced a flow rate of 300 to 500 ml per minute with approximately 40 strokes per minute. The Army unit could not be cleaned, and the testing was terminated when the filter clogged and the water delivery rate dropped to <180 ml per minute.

(3) Sampling--On operational days 1 - 5 and days 6 - 10, fifteen liters of test water were pumped through each KPF unit. Microbiological samples were taken for analyses on days 1, 3, 5, and after a 48-hour stagnation period for general water tests; and on days 6, 8, 10, and after a 48-hour stagnation period for worst case challenge water tests. During the sample collection period, the intake hose was disconnected from the large challenge tank and placed into the separate smaller challenge vessel which additionally contained Cryptosporidium oocysts (Figure 6). First, a 500 ml volume of the filtered water was measured and discarded; then the next 1500 ml volume was collected in a sterile graduated cylinder for analysis. When the 48-hour stagnation tests were performed (after days 5 and 10), the first 1500 ml volumes of water passing through the units were collected for sampling.

Water characteristics, filtered water volumes, and sample collections for analyses for the Army prototype charcoal filter unit were the same as described for the Katadyn ceramic candle filters.

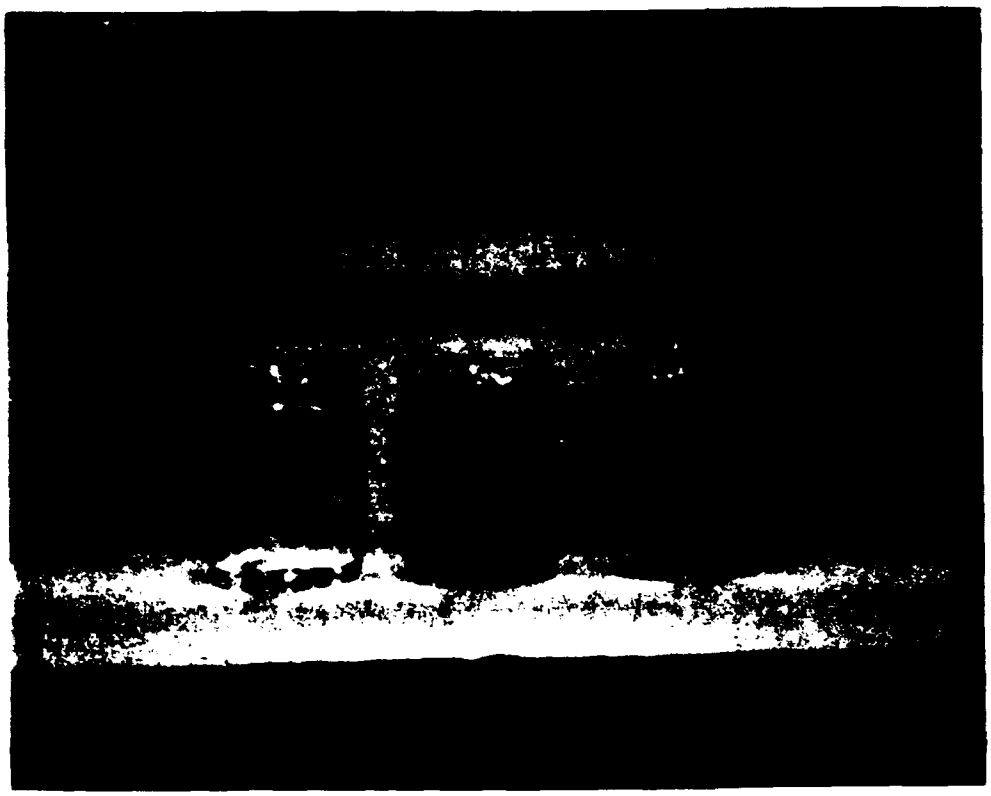

Figure 5. Challenge waters Beakers 1, 2, 3

1. Criteria for purifier acceptability and protocol monitoring

(1) Criteria--The provisional USEPA "Guide Standard and Protocol for Testing Microbiological Water Purifiers" states a minimum microbiological reduction requirement of 6 logs or 99.9999% for the bacterial challenge. The minimum reduction is 3 logs or 99.9% for protozoan cysts and cyst simulants. Also, to be considered acceptable, the purifiers must remove the above required amounts of challenge organisms at least 90% of the time, and then, never achieve less than 5-log removals for bacteria and 2.5-log removals for protozoan oocysts.

(2) Protocol monitoring--The test waters were monitored each test day to insure that nonmicrobiological challenge parameters were at required levels. Adjustments were made as needed, especially pH changes during runs.

(3) Microbiological contaminant monitoring--During the short-term testing, it became apparent that a noncoliform micro-organism had colonized the KPF. Efforts were conducted to determine the source and identification of the organisms in samples and from test water constituents. The organism was examined by gram stain, morphological characterization microscopically, growth on selective isolation media, and biochemical tests using the OXI/FERM TUBE® (Roche Diagnostic Systems, Nutley, NJ).

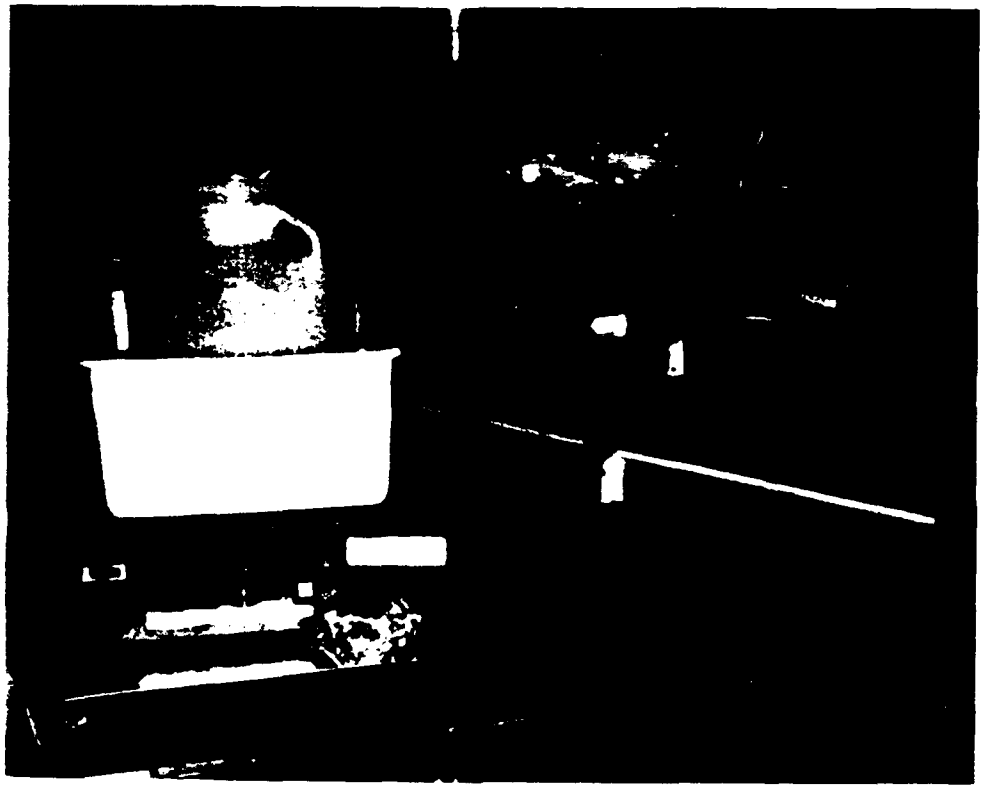

Figure 6. Cryptosporidium oocysts challenge vessel

2. LONG-TERM FILTRATION TESTS

a. Microbiological challenges

(1) Bacteria--All bacterial preparation and assay methods were as described in the short-term tests above.

(2) Cysts/simulants

(a) Stock preparation--All cyst and simulant preparations were as described in the short-term tests above.

(b) Preparation for tests--Preparation remained as described in short-term tests above.

(c) Assay procedures--Because of the difficulty in visual differentiation and quantitation of Rhodotorula rubra yeast in the worst case water, the method was changed to the membrane filter technique with YM medium. Yeast sample dilutions were made in dd H_2O containing 0.01% Tween 20 (added to prevent clumping). Rhodotorula rubra yeast cells were quantitated by filtration of triplicate 1.0 ml aliquots of diluted sample through the 47 mm Millipore membrane filters (Type HAWG 0.45 μm pore size). Each filter was placed on a 47 mm pad, which contained 2.0 ml of pH 3.3 YM broth, in a 50 X 9 mm snap cap petri dish (Falcon # 1006). Plates were incubated at 26°C for 60 hours, and the pink colonies were counted. No natural yeast contaminants (colorless colonies) were observed with this method.

b. Test water characteristics

(1) Preparation--USEPA (Test water # 3) worst case challenge water containing SAE fine test dust, humic acids, high total dissolved solids (TDS), and a pH of 9.0, (conditions identical to those described in the short-term challenge test phase), were prepared.

c. Testing procedures

(1) Test set up--As in the short-term study, all of the microbiological challenge organisms were present throughout the filter testing runs in the large tank, except for the Cryptosporidium parvum oocysts. Again, cysts were added to a small tank of the challenge water, and all parameters were sampled from this container at the appropriate sampling periods. Initially, Katadyn filter Unit 2 (Serial # 74941) and Unit 3 (Serial # 74781), used in the short-term studies, along with a new unit (Serial # 60335) were selected for the long-term worst case challenge water tests. These Katadyn filter units were operated by connecting them individually to a different large cam-type piston pump, which was an inhouse built "wear-tester" unit mounted on a table powered by a one hp electrical motor (Figure 7). Each filter housing was secured by a clamp attachment mounted on the table, and the filter pump shaft was screwed into the cam-operated arm extension attached to a pulley. The pump stroke rate was controlled by a rheostat mounted on the table. The filter unit intake hose was connected to the supply tank, and the product was collected from a sterile rubber tube attached to the spout of the filter unit (Figures 8,9). None of the three initial KPF units could withstand the pressures produced by the "wear-tester," and all three experienced gross candle failure within 35 liters of water throughput. The failure was detected by visual turbidity and confirmed by Klett-Summerson turbidity measurements of the product water. The ceramic candles were disinfected and sent to Katadyn Corporation for evaluation, where it was determined that the end gaskets had failed because of the pressures exerted on them.

Figure 7. Cam-type piston pump unit

New second generation ceramic candle filters, # 87719 and # 87667, for the KPF were subsequently supplied by Katadyn Corporation for additional long-term testing. These were improved by incorporating reinforced end gaskets. Katadyn Corporation also supplied a filter housing (Figure 10) with an attached pressure gauge (manometer); thus, pressure could be monitored accurately during water filtration, and the pump stroke frequency could be adjusted downward as the ceramic candles became clogged and feed water pressures increased.

(2) Test operation--During the long-term tests with the second generation KPF, operating pressures were maintained at approximately 13.5 bars (1 bar = 14.7 lb./sq. inch (psig). Initially, approximately 730 ml/minute of filtered water was produced at a manometer pressure of 13 bars with the wear tester pump motor rheostat dial set at 10 (56 strokes/minute). The

testing cut-off point for candle cleaning, as agreed upon through conversations with the manufacturer, occurred when the volume of product water dropped to 250 ml, at a manometer pressure of 13.5 bars (198 psig) with the rheostat setting lowered to 4.5 (22 strokes/minute). This occurred within approximately every 15-25 liters of challenge water throughput. At that time the ceramic candles were removed, scrubbed with the KPF brush/scrubber, and rinsed in dd H_2O. The units were then reassembled and operated again until plugged or the operating day concluded. (Daily operations always were continued until the units plugged, after which they were cleaned and kept disassembled until the next operating day for drying.) Typically, daily test operations allowed the throughput of 20 gallons of challenge water for each test filter.

(3) Sampling--Sampling was conducted soon after start-up at 15 liters), and at every 50 gallons of throughput. The product water samples were always collected from the filter units prior to cleaning.

Figure 8. Mounted KPF unit operated by rheostat controls

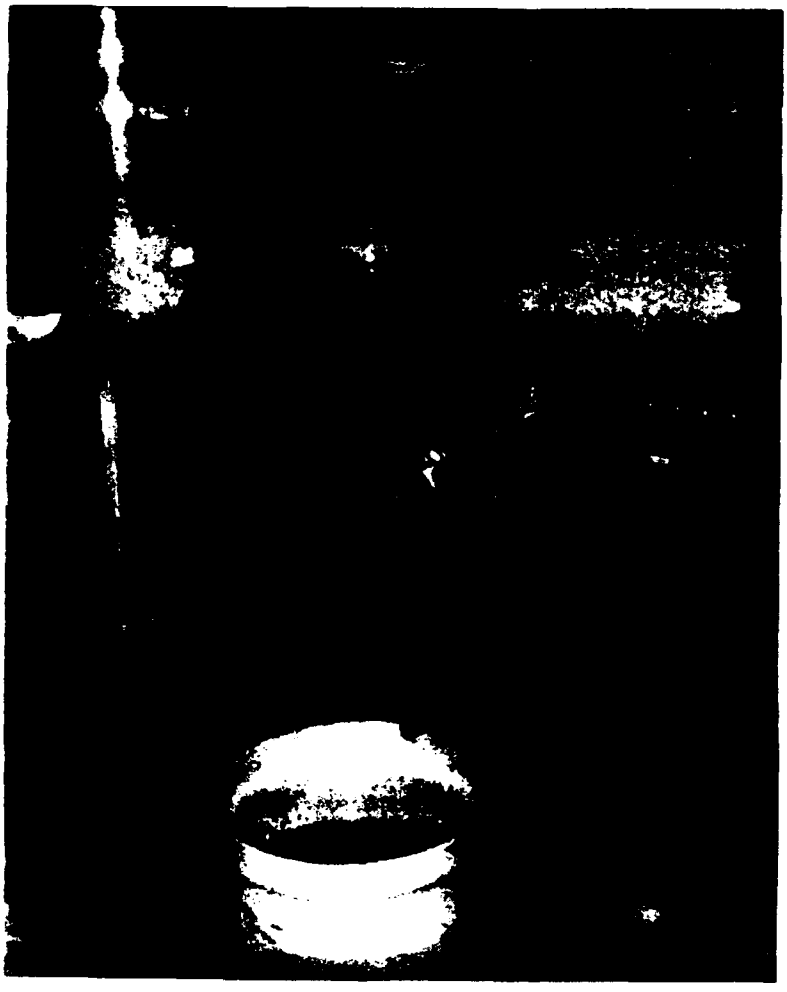

Figure 9. Collection of product water

3. SILVER LEACHING TESTS

a. Challenge water--The USEPA Guide Standard, Section 3.3.5 Test Water #5 (Leaching Test Water for Units Containing Silver) states the water should contain specific characteristics as follows: Free of residual chlorine; pH - 5.0 ± 0.2; TOC - approximately 1.0 mg/liter; Turbidity - 0.1-5 NTU; Temperature - 20°C ± 5°C; and TDS - 25-100 mg/liter.

After dechlorination, the challenge water was prepared for stressed leaching tests of the ceramic candle filters. The TOC was adjusted to approximately 1.0 mg/liter; turbidity to <1.0 NTU; TDS to 70-80 mg/liter; temperature to 23°C; and a final pH of 4.9-5.0 (using 1.0 N HCl).

b. Analytical methods for silver--On the first test day, one liter samples were taken from the challenge water reservoir to determine background levels, from the filtered product water collection tank after five liters throughput, and from the filter unit at 15 liters throughput of product water. On day 2, the one liter sample was collected at the beginning of a 30-liter filtration run. After the 48-hour stagnation sample, the first liter of filtered product water was collected. All samples were adjusted to pH 2.0 with Ultrex nitric acid at the time of collection, and were stored at room temperature in the dark until assayed. Samples were analyzed with an Atomic Absorption Spectrophotometer, Perkin-Elmer Model 3030, equipped with an air-acetylene burner head and Ag^+ hollow cathode lamp.

RESULTS

1. SHORT-TERM STUDIES

Preliminary studies had indicated that, over time, there was a reduction in the numbers of micro-organism and simulant challenge due to their adsorptive attraction to the surfaces of the challenge water containers. Therefore, a replicate study was initiated to determine percent losses over a 3-hour time period, corresponding to the maximum period required for filtration of the three KPF units at 15 liters per hour each, using general test water. Results shown in Table 1 reflect that surface area losses averaged 24.99% for beads, 18.81% for yeasts, and 7.33% for oocysts over 3 hours. All determinations of filtration removal efficiency in the tests were adjusted for average surface losses, accordingly.

Short-term test results for removals of the challenge organisms by the Katadyn ceramic filter units are summarized in Table 2 below. It can be seen that the units prevented passage of all test organisms and simulants until day 5, when units one and three passed excessive amounts of Klebsiella. On day 5, unit three also passed some latex beads, yeasts, and Cryptosporidium cysts. During the first 48-hour stagnation test (beginning after the 5th operational day), unit one again passed the Klebsiella and the latex bead cyst simulants; but neither of the other units passed any challenge materials. On operating day 6 (first day of worst case water challenge), all filter units met the test organism criteria for removal. However, on day 8, all of the challenge parameters broke through unit one in high numbers. On operational day 10, the Klebsiella were observed in the samples from units one and three; and the cyst simulants also were observed from unit one. During the final 48-hour stagnation test, with worst case challenge water, the Klebsiella were noted in all three units. Cyst simulants again were detected in the 48-hour stagnation sample for unit one, but not at levels exceeding the criteria. To summarize, overall Klebsiella removals in Katadyn product water for all three test units

exceeded the USEPA guide standard criteria. Unit one failed the test for Cryptosporidium cyst removal; however, the other two units passed the guide standard criteria for cysts and simulants. Thus, the KPF would be considered to have passed the test.

TABLE 1. Surface Area Losses of Challenge Materials

Hours	Yeast	% Loss	Beads	% Loss	Oocysts	%Loss
0	2.06×10^7	-	2.01×10^7	-	2.08×10^6	-
0.5	1.79×10^7	13.12	1.56×10^7	22.38	1.93×10^6	7.21
1	1.75×10^7	15.03	1.63×10^7	18.90	1.93×10^6	7.21
2	1.55×10^7	24.76	1.41×10^7	29.85	1.95×10^6	6.25
3	1.60×10^7	22.33	1.43×10^7	28.85	1.90×10^6	8.65
Avg.		18.81		24.99		7.33

TABLE 2. Katadyn Filtration Effectiveness Summary - Short Term Tests

Day	Challenge	Inoculum	Unit 1 Recovery/L	Unit 1 %Reduction	Unit 2 Recovery/L	Unit 2 % Reduction	Unit 3 Recovery/L	Unit 3 % Reduction
			General Water					
1	K. terrigena	1.13×10^8	*[a]	>99.9999	*	>99.9999	*	>99.9999
	R. rubra	1.81×10^7	*	>99.9	*	>99.9	*	>99.9
	Beads	1.40×10^7	*	>99.9	*	>99.9	*	>99.9
	C. parvum	1.90×10^6	*	>99.9	*	>99.9	*	>99.9
3	K. terrigena	1.00×10^8	*	>99.9999	*	>99.9999	*	>99.9999
	R. rubra	1.38×10^7	*	>99.9	*	>99.9	*	>99.9
	Beads	1.22×10^7	*	>99.9	*	>99.9	*	>99.9
	C. parvum	1.46×10^6	*	>99.9	*	>99.9	*	>99.9
5	K. terrigena	1.53×10^8	5.47×10^3	99.9964	*	>99.9999	OVERGROWN[b]	
	R. rubra	1.07×10^7	6.10×10^3	99.9430	*	>99.9	2.27×10^4	99.7879
	Beads	4.91×10^6	*	>99.9	*	>99.9	2.66×10^4	99.4582
	C. parvum	1.29×10^6	*	>99.9	*	>99.9	8.96×10^3	99.3054
48 Hr Stag.	K. terrigena	1.00×10^8	3.33×10^4	99.9667	*	>99.9999	*	>99.9999
	R. rubra	1.66×10^7	4.88×10^3	>99.9	*	>99.9	*	>99.9
	Beads	9.03×10^6	1.38×10^4	99.8281	*	>99.9	*	>99.9
	C. parvum	2.03×10^6	*	>99.9	*	>99.9	*	>99.9
			Worst Case Water					
6	K. terrigena	1.00×10^8	*	>99.9999	*	>99.9999	*	>99.9999
	R. rubra	1.36×10^7	*	>99.9	*	>99.9	*	>99.9
	Beads	1.52×10^7	*	>99.9	*	>99.9	*	>99.9
	C. parvum	1.59×10^6	*	>99.9	*	>99.9	*	>99.9
8	K. terrigena	1.10×10^8	1.24×10^5	99.8873	*	>99.9999	*	>99.9999
	R. rubra	1.03×10^7	3.65×10^4	99.6456	*	>99.9	*	>99.9
	Beads	8.80×10^6	2.99×10^4	99.6602	*	>99.9	*	>99.9
	C. parvum	1.09×10^6	1.66×10^3	99.8477	*	>99.9	*	>99.9
10	K. terrigena	9.33×10^7	5.33×10^4	99.9429	*	>99.9999	2.00×10^3	99.9979
	R. rubra	1.74×10^7	2.62×10^4	99.8468	*	>99.9	*	>99.9
	Beads	1.43×10^7	2.90×10^4	99.7972	*	>99.9	*	>99.9
	C. parvum	1.83×10^6	*	>99.9	*	>99.9	*	>99.9
48 Hr Stag.	K. terrigena	1.10×10^8	1.67×10^3	99.9985	3.30×10^3	99.9970	1.00×10^4	99.9909
	R. rubra	1.39×10^7	5.92×10^3	99.9574	*	>99.9	*	>99.9
	Beads	1.37×10^7	5.92×10^3	99.9568	*	>99.9	*	>99.9
	C. parvum	1.43×10^6	*	>99.9	*	>99.9	*	>99.9

a = Zero or below detection limits.

b = unable to count individual pink or green colonies.

As noted in Table 3, the Army prototype filter unit started passing excessive levels (greater than the USEPA Guide Standard criteria) of the Klebsiella test organisms beginning at day 5, and the levels increased through day 6 (the last test day that this unit was evaluated), at which time removals were reduced to only 99.98%. The unit also was observed to pass the latex bead simulant at levels exeeding the USEPA Guide Standard at the first stagnation period (after day 5). Additionally, on these later two sampling days the opportunistic organisms, which were found in the Katadyn unit samples, also had colonized this filter unit (Table 4).

TABLE 3. Army Filter Summary

Day	Organism Challenge	Challenge/Liter Inoculum	Recoveries/Liter Army Unit 1	%Reduction
		General Water		
1	K. terrigena	1.00×10^3	6.00×10^1	>99.9999
	R. rubra	1.38×10^7	*[a]	>99.9
	Beads	1.22×10^7	*	>99.9
	C. parvum	1.46×10^6	*	>99.9
3	K. terrigena	1.53×10^3	4.00×10^1	>99.9999
	R. rubra	1.07×10^7	*	>99.9
	Beads	4.91×10^6	*	>99.9
	C. parvum	1.29×10^6	*	>99.9
5	K. terrigena	1.07×10^8	3.00×10^2	99.9997
	R. rubra	1.61×10^7	*	>99.9
	Beads	5.59×10^6	*	>99.9
	C. parvum	1.59×10^6	*	>99.9
48 Hr Stag	K. terrigena	1.10×10^3	2.00×10^2	99.9998
	R. rubra	1.69×10^7	*	>99.9
	Beads	1.10×10^7	2.72×10^4	99.7527
	C. parvum	1.75×10^6	*	>99.9
		Worst Case Water		
4	K. terrigena	1.00×10^3	1.83×10^4	99.9817
	R. rubra	1.36×10^7	*	>99.9
	Beads	1.52×10^7	1.04×10^3	>99.9
	C. parvum	1.59×10^6	*	>99.9
7	Discontinued[c]			

a = Zero or below detection limits.
b = Exceeded removal requirements.
c = Discontinued because Army prototype filter clogged.

Although not a part of the original test, it was also observed that opportunistic bacteria capable of growing on m-Endo broth (the Klebsiella detection/quantification medium) were found in the product water from one of the KPF units beginning on operational day 3 of the test (Table 4). The contaminant colonies were pink and were readily distinguishable from the metallic green sheen of the Klebsiella. By operational day 8 all product waters of the three KPF units and the Army unit were contaminated by these organisms; and by the end of the test they were observed at levels exceeding 10^5/liter, which surpasses USEPA recommendations for heterotrophic plate count bacteria in drinking water. Microscopic and biochemical tests indicated the contaminant bacterium was a pseudomonad, possibly P. putida, fluorescens or aeruginosa. Even though the KPF ceramic surfaces were scrubbed, the level of contamination did not decrease. This would indicate that the contaminant was present at high concentrations on the inside (or product side) of the filter surfaces, especially since this contaminant was below our detection limits in the unfiltered challenge water.

TABLE 4. Filter Contaminant Colonization/Liter

Day	Katadyn Unit 1	Katadyn Unit 2	Katadyn Unit 3	Army Unit
1	-[a]	-	-	-
3	-	-	2.27×10^2	-
5	3.20×10^3	-	Overgrown[b]	-
48 Hr Stag	6.67×10^4	5.20×10^4	1.03×10^6	$>1.00 \times 10^5$[c]
6	1.13×10^4	$>1.00 \times 10^5$	$>1.00 \times 10^5$	1.80×10^4
8	3.67×10^3	5.33×10^3	1.80×10^4	
10	1.00×10^4	6.67×10^3	1.07×10^4	
48 Hr Stag	7.00×10^3	3.90×10^3	6.83×10^3	

a = Zero or below detection limits for dilutions tested.
b = Unable to count individual pink or green colonies.
c = Exceeded 100 colonies on 47 mm membrane filter.

2. LONG-TERM STUDIES

Table 5 below summarizes the history of the three Katadyn ceramic filter units which failed the initial long-term tests (two used in the short-term studies along with one new ceramic filter). It can be seen that the two KPF used in the short-term tests generally performed adequately during the initial period of filtration with the worst case challenge water; but, by the time about 20 liters of this worst case water had passed, they broke catastrophically due to the high pressures exerted upon them when they began to foul with the challenge constituents.

TABLE 5. Katadyn Filter Operating History

Challenge Water EPA Test Criteria	Test Days	Liters/ Day	Filter Cleaned	Failed Challenge For Bacteria	Beads	Cysts
Ceramic Cartridge Serial # 74941 (Unit 2)						
General Test	1	15				
1 NTU	2	15				
	3	15				
	4	15				
	5	15				
48 Hr. Stag.		2	Yes			
Worst Case	6	15	Yes			
30 NTU	7	15	Yes			
	8	15	Yes			
	9	15	Yes			
	10	15				
48 Hr. Stag.		2	Yes	Yes		
Long-Term Test						
Worst Case	11	20	Yes			
10 NTU	11	16		Gross Structural Failure[a]		
Total		190				
Ceramic Cartridge Serial # 74781 (UNIT 3)						
General Test	1	15				
1 NTU	2	15				
	3	15				
	4	15				
	5	15		Yes	Yes	Yes
48 Hr. Stag.		2	Yes			
Worst Case	6	15	Yes			
30 NTU	7	15	Yes			
	8	15	Yes			
	9	15	Yes			
	10	15		Yes		
48 Hr. Stag.		2	Yes	Yes		
Long-Term Test						
Worst Case	11	21	Yes	Gross Structural Failure		
10 NTU						
Total 2		175				
Serial # 60335 (New Cartridge placed in Unit 1 housing assembly)						
Long-Term Test						
Worst Case	1	20	Yes			
10 NTU	1	15		Gross Structural Failure[b]		
Total		35				

a = Total amount of test dust turbidity collected by filter = 470 mg
b = Total amount of test dust turbidity collected by filter = 441 mg

Initially, it was thought that the SAE fine dust, which provided the major turbidity component, was responsible for clogging the ceramic filter candles. Therefore, the original intention for the long-term test was to modify the turbidity level to 10 NTU with the hope of passing 3 times as much water between candle cleanings as the 30-NTU levels. It was found, however, that the amount of water passed before clogging under the test conditions at 10 NTU was significantly less than at 30 NTU (Table 6).

TABLE 6. Turbidity vs. Filtered Water Volumes

SAE Test Dust Turbidity (NTU)	Liters of Challenge Water Filtered Between Cleaning	Total Liters Filtered	Averaged Liters Between Cleaning
5	15 - 10 - 15 - 12.5 - 12.5	65	13
10	18.7 - 18.7 - 15 - 15 - 14 15 - 15	98.4	24.1
20	18 - 20	38	19
30	21 - 22 - 24 - 25 - 27 - 23 22.5 - 25 - 27 - 29 - 28.5 22 - 20	319	24.5
40	32.5 - 24 - 23.5 -24	104	26

After several small experiments were performed (using the new ceramic cartridge filter units with reinforced end gaskets), it was determined that the SAE test dust was not the major clogging factor for the ceramic candles, but rather the humic acids at 10 mg/liter were responsible. Apparently, the SAE dust actually served to extend the water filtering capacity since the dust captured some of the humic acids before they could reach the ceramic candle surface and foul it. Following the addition of 10 mg/liter of humic acids the challenge water read 64 NTU. The KPF filtered water, however, still retained a significant amount of humic acid color (17-22 units retained vs. 34-36 units initially as measured by the Klett-Summerson colorimeter). Further tests revealed that a 0.2 µm polycarbonate membrane filter would retain over 50% of the humic acids. Also, it is likely that the challenge organisms and simulants may have contributed to clogging the filters, but this was not investigated. For the long-term studies the SAE test dust levels were maintained in the challenge waters at 30 NTU.

The results of the studies on the two ceramic filter cartridge units show that they performed well, and in most cases no organisms were recovered at the detection levels available for the test (Tables 7 and 8).

A problem was encountered with several of the Klebsiella assays in that the pH of the phosphate buffered saline used to wash and dilute the organism was incorrect (pH 4-5), which may have reduced the viability of the organisms in the assay procedure. For that reason, where possible, additional samples were taken and assayed as soon as the problem became known.

TABLE 7. Katadyn Filter Challenge Results--Long-Term Studies
Filter Unit #87719

Gallons Thru-Put	Turbidity (NTU)	Challenge	Inoculum/L	Recovery/L	Percent Removed
3.9	10	K. terrigena	1.0×10^8	<3[a]	>99.9999[b]
		R. rubra	1.1×10^7	<3	>99.9
		Beads	1.3×10^6	<1000	>99.9
		C. parvum	8.5×10^5	<1000	>99.9
50	5	K. terrigena	1.1×10^8	33	>99.9999
		R. rubra	1.5×10^7	<3	>99.9
		Beads	1.8×10^7	<1000	>99.9
		C. parvum	1.4×10^6	<1000	>99.9
102	30	K. terrigena	1.1×10^7[c]	<3	>99.9999
		R. rubra	2.8×10^7	20	>99.9
		Beads	2.6×10^7	<1000	>99.9
		C. parvum	1.9×10^6	<1000	>99.9
106	30	K. terrigena	1.1×10^7	<3	>99.9999
		R. rubra	2.0×10^7	<3	>99.9
		Beads	9.1×10^6	<1000	>99.9
		C. parvum	1.1×10^6	<1000	>99.9

[a] = less than the detection limit for the assay used in the test.
[b] = greater than the percent removal required by the USEPA Guide Standard.
[c] = pH of the phosphate buffered saline used for preparation washing and sample dilution of Klebsiella was below optimum levels.

TABLE 8. Katadyn Filter Challenge Results - Long-Term Studies
Filter Unit # 87667

Gallons Thru-Put	Turbidity (NTU)	Challenge	Inoculum/L	Recovery/L	Percent Removed
3.9	30	K. terrigena	1.1×10^{7}[a]	<3[b]	>99.9999[c]
		R. rubra	2.8×10^{7}	<3	>99.9
		Beads	2.6×10^{7}	<1000	>99.9
		C. parvum	1.9×10^{6}	<1000	>99.9
51	30	K. terrigena	6.7×10^{7}[a]	<3	>99.9999
		R. rubra	2.8×10^{7}	6.7	>99.9
		Beads	2.1×10^{7}	<1000	>99.9
		C. parvum	1.4×10^{6}	<1000	>99.9
30	30	K. terrigena	1.1×10^{7}	<3	>99.9999
		R. rubra	2.0×10^{7}	10	>99.9
		Beads	9.1×10^{6}	<1000	>99.9
		C. parvum	1.1×10^{6}	<1000	>99.9
100	30	K. terrigena	1.3×10^{8}	<3	>99.9999
		R. rubra	2.3×10^{7}	10	>99.9
		Beads	1.9×10^{7}	<1000	>99.9
		C. parvum	1.6×10^{6}	<1000	>99.9
121	30	K terrigena	1.1×10^{8}	<3	>99.9999
		R. rubra	1.0×10^{7}	<3	>99.9
		Beads	1.5×10^{7}	<1000	>99.9
		C. parvum	1.2×10^{6}	<1000	>99.9

[a] = pH of the phosphate buffered saline used for washing and sample dilution of Klebsiella was below desirable levels.
[b] = less than the detection limit for assay used in the test.
[c] = greater than the % removal required by EPA guide standard.

Efforts were made to comparatively evaluate the effective pressures that could be attained by manual vs. mechanical operation of the KPF units. The results demonstrated that the filters could readily be pumped at high stroke rates either mechanically or, for short periods, by hand. When the filter candles were clean, it was not difficult to obtain 60-80 strokes per minute with a volume throughput of 750-900 ml and at a manometer pressure of around 10 bars (≈150 psig) by hand pumping. When the ceramic candles were nearly clogged it became difficult to hand pump more than 20 strokes per minute, with volume throughputs of around 200 ml, and the pressures on the manometer around 18-20 bars (≈260-290 psig). These hand-pumping characteristics exceeded the pressure and stroke rates exerted by the mechanical pumping procedures used in the studies which were described in the testing procedures for the long-term filtration tests, 2.c.(2).

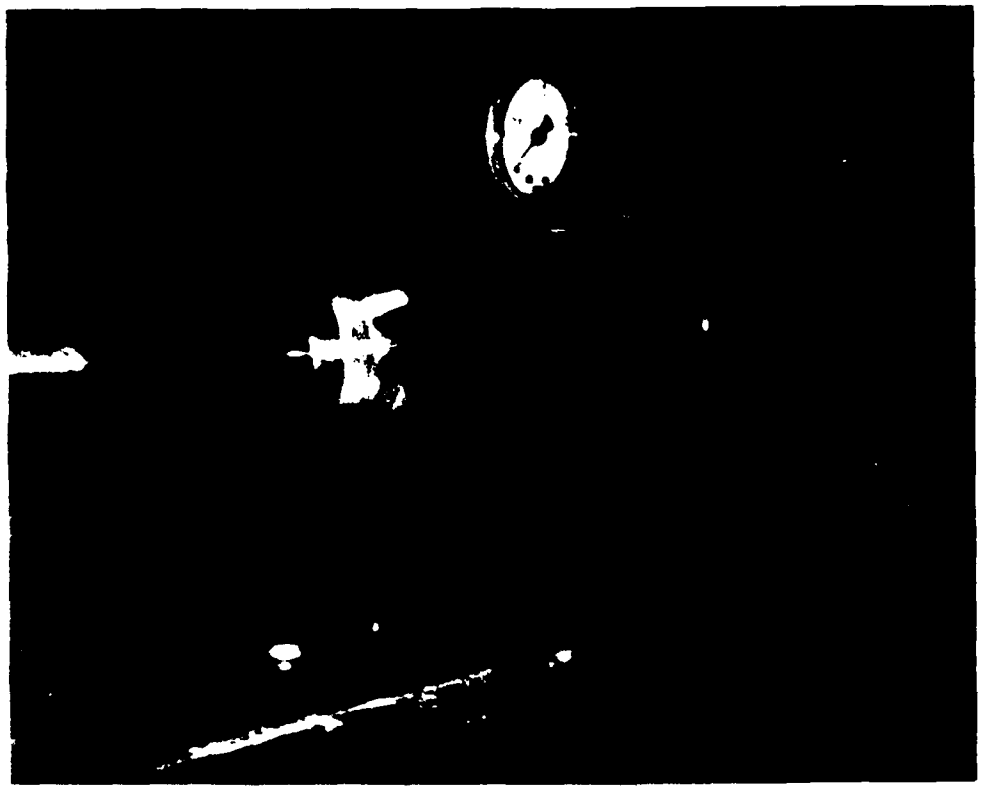

Figure 10. KPF housing with pressure gauge (manometer)

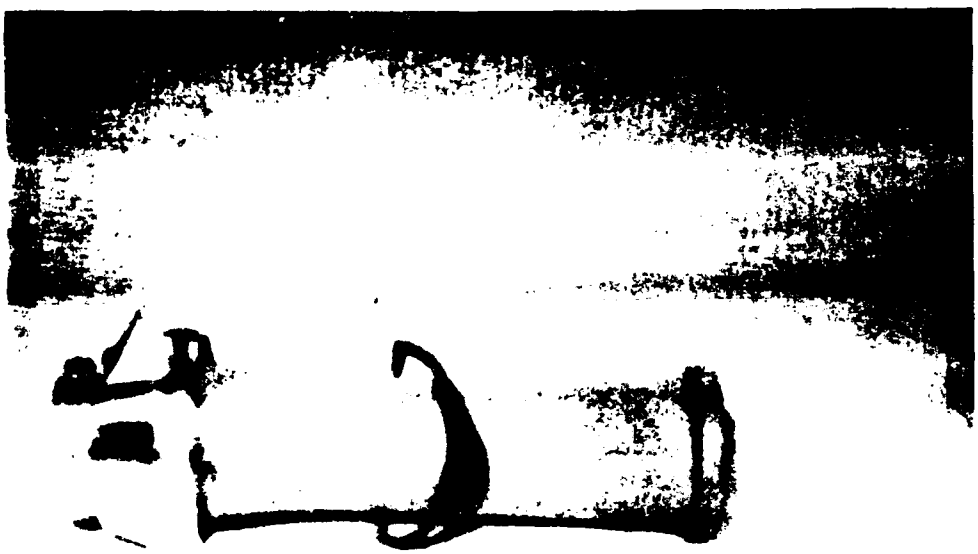

Figure 11. Gauge used to determine wear of ceramic handles

When the maximum-use life of the ceramic candles was reached, as determined with the feeler gauge (Figure 11) provided by Katadyn Corporation, a final test was performed to determine the maximum pressures that the filter units used in the long-term study could withstand. Measurement of the ceramic candles with the gauge indicated that both filters had reached their maximum usage due to the frequent scrubbings during the worst case water studies. Figure 12 shows a new ceramic candle and one of the worn ceramic candles that had reached maximum-use life. For the final test Unit # 87667 was brushed using the bristles but not scrubbed with the scouring pad; Unit # 87719 was brushed and scrubbed. To study catastrophic filter candle failure, worst case challenge water was prepared. Previous studies had shown that a residual turbidity of 17-22 NTU was typical for product water due to the humic acids in the challenge water which pass through the ceramic candles during filtration. Product water sampling was done at the beginning of the failure test, after the candles were loaded, at the point where a "pop" was heard and visual turbidity was observed, and, finally, after another small amount of pumping. Pressure was increased on the manometer by 5 bars every 2 minutes until the filters failed (see failed ceramic candle at Figure 13). Results are shown in Table 9.

TABLE 9. Maximum Pressure vs. Filter Failure

Manometer Bars	Filter Status	Time/Pump Strokes	Product Water Turbidity (NTU)	Pump Rheostat Setting	Liters Filtered
		Filter Unit Serial # 87667			
5	Preload	Zero	18	10	
15	Loaded		18	4.5	13
20	Burst	4-5 strokes	124		
0	After Burst	25 strokes	69		
		Filter Unit Serial # 87719			
7	Preload	Zero	20	10	
15	Loaded		18	4.5	16
20		2 minutes	18		≈1
25		2 minutes	18		1.24
30	Burst	≈1 minute	95		≈1.04
0	After Burst	10 strokes	69		

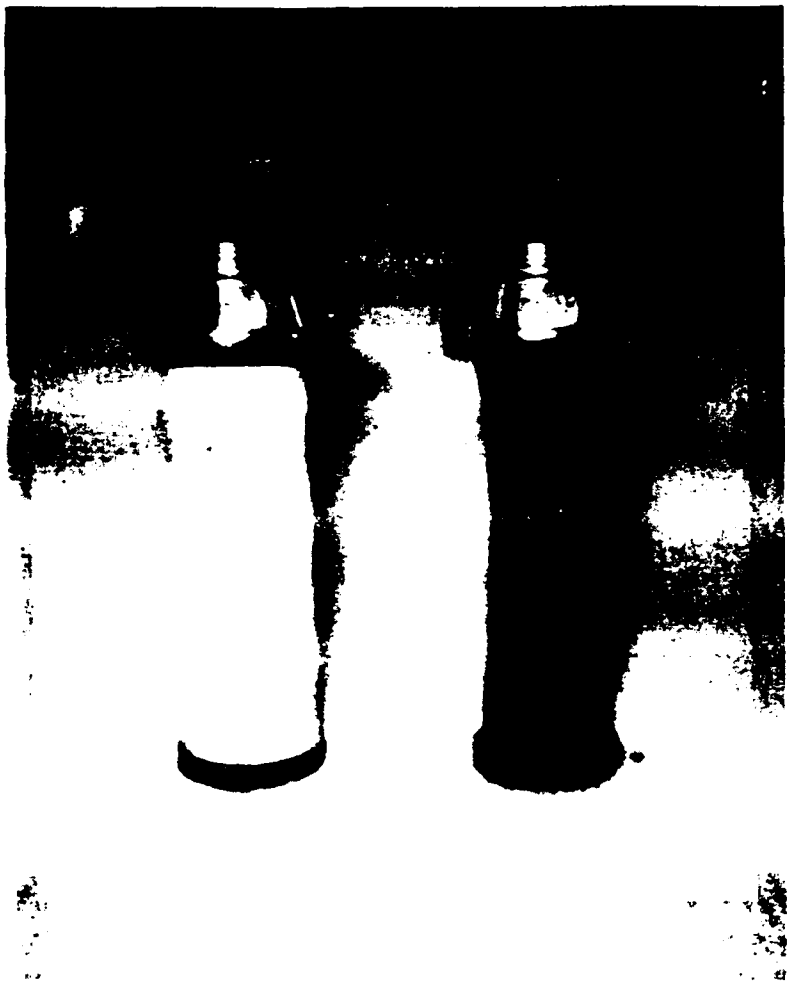

Figure 12. New ceramic candle vs. worn candle

1. SILVER LEACHING TEST

The challenge waters were made conducive to leaching as designated in the USEPA protocol. As seen in Table 10, when the Katadyn ceramic filter was first used, the bacteriostatic silver level in a liter of product water was approximately 1.49 mg/liter (nearly 30 times the USEPA recommended level). Although silver levels dropped after 15 and 30 liters of water had been produced, the silver level again increased to 0.32 mg/liter immediately after the 48 hour stagnation period. The test results indicate that the ceramic candle unit allowed silver to leach into the product water at a level which exceeds the USEPA's allowable maximum of 0.05 mg/liter for lifetime consumption.

TABLE 10. Silver Leaching Test Results From Water Produced by a Katadyn Filter Unit

Day	Water Sample Test Point	mg/liter Silver Residual
1	Prepared water storage tank (Background)	0.04
1	Product water after 5 liters	1.49
1	Product water after 15 liters	0.09
2	Product water after 30 liters	0.06
48 Hour Stagnation	Product water after first liter	0.32

Figure 13. Failed ceramic candle

HEALTH HAZARD ASSESSMENT

1. HEALTH HAZARD ISSUES

Based on these in-house results, documented information and publications,[3,4,10,11,12] and personal communications,[9,13] some potential health hazards have been identified and recommendations suggested.

a. Personal contamination by pathogens during cleaning--Use of the KPF necessitates the occasional or even frequent cleaning of the ceramic filter candle to remove waterborne turbidity, including the microorganisms which are filtered out of the water by the 0.2 micron filter.[3] The organisms which are filtered out are not killed by the filtration process and may be concentrated to very high numbers on the filter surface, especially in highly contaminated water which is possible in combat situations (e.g., sewage laden water). Cleaning of the ceramic filter, which is necessary to sustain maximum water production, requires disassembly of the unit and the scrubbing of the material clogging the filter with a hand-held brush. During this process it is difficult not to contaminate the hands since the filter unit and the ceramic filter candle are held by hand. This puts the skin of the hands in contact with organisms at levels which could be hundreds of times greater than found in the water source. Some waterborne disease organisms which may be scrubbed from the filter surface, such as schistosomes, are able to penetrate the skin directly; others, like most of the enteric pathogens, could be ingested through contact of the mouth by contaminated hands or other forms of improper sanitation. In a similar manner the brush provided with the KPF to clean the filter candle will become highly contaminated and could then contaminate the KPF and carrying case, potentially bringing pathogens in contact with the user at a later time, since this brush goes into the case for carrying along with the unit.

b. Potential filter failure from extreme pumping pressures--The ceramic filter candles of the KPF are designed to operate under high-pumping forces of equal to or greater than 22 bars pressure or 322 psig.[9] However, as observed during catastrophic failure tests on KPF that had attained their expected use life through wearing away of the ceramic filter material (as determined with the feeler gauge), the units could break apart before 22 bars pressure was reached. In laboratory tests the hand-operated pump pressures attained by several different laboratory personnel ranged from around 13 to 18 bars. It is reasonably assumed that soldiers in excellent physical condition could attain at least 20 bars pressure using the device by hand as per instructions, especially if the unit can be placed on a firm surface for leverage. It is not unlikely that if leverage on the pump is increased by mechanical means, the design pressures could be exceeded and catastrophic failure could occur,

possibly even before the ceramic material on the units was worn away from repeated cleaning. A report concerning tests of the KPF for the U.S. Army Airborne Board revealed that soldiers consider the pumps hard to operate.[10] Because they find the pumps difficult and tiring to operate, soldiers may look for ways to increase water production; and they could attempt to establish an increased mechanical leverage in a field setting (e.g., use of a hammer or adaption of pump handle for use of the feet). If catastrophic failure or even minor failure occurs, large numbers of microorganisms would likely come off the filter surface, go through the break in the ceramic candle, and contaminate the product water. Consumption of this water could lead to a significantly increased risk of infectious disease, even in the presence of the post-filtration disinfectants.

c. Silver leaching in excess of USEPA Drinking Water Criteria--Silver leaching tests using the USEPA's interim Guide Standard and Protocol for Testing Microbiological Water Purifiers indicated that the KPF unit product water exceeded the USEPA's allowable silver maximum for lifetime consumption. High levels of silver consumption can lead to some minor health effects. The main chronic effect is argyria, which is a graying of the skin and internal organs; however, 1 gm of total silver accumulation in the body is needed to achieve this effect. Calculations of a safe Average Daily Intake yields 182 micrograms/day.[11] Animal studies indicate that large single doses of colloidal silver (500mg) can be fatal.[12]

2. HEALTH HAZARD RECOMMENDATIONS

a. Personal contamination by pathogens during cleaning--Military personnel need to be made aware during their training on the KPF that the ceramic candle filter surface may become highly contaminated with pathogenic microorganisms, especially in highly suspect contaminated waters receiving sewage, to which their hands and other skin surfaces may be exposed during the cleaning process. Personnel must be instructed that, where possible, the hands and other exposed skin surfaces should be washed well with soap and/or disinfected immediately after cleaning and reassembly of the KPF. The unit's outer surface should also be cleaned, especially the product water spout, to remove residual microbial contaminants which may have been spread about during the cleaning process. If available, a disposable rag or material of low water porosity (e.g., latex gloves or a thin plastic sheet) should be used to hold the candle to reduce skin exposures to the turbidity and microorganisms being scrubbed from the candle. Spent KPF candles should be disposed of in plastic garbage bags or buried. The KPF cleaning brush should also be cleaned by vigorous rinsing in water and, if possible, disinfection before repacking in the kit.

As a product improvement, it is recommended that a separate waterproof section of the carrying case be incorporated for the brush to prevent contamination of the KPF.

b. Potential filter failure from extreme pumping pressures--Recommend that military personnel using the KPF be thoroughly instructed that the ceramic candle is designed to operate only by hand and that exertion of excessive pressures on the pump could cause catastrophic failure of the unit's ceramic filter material. Additional mechanical leverage should especially be cautioned against since the candles are not necessarily designed to withstand high pressures, especially a high instantaneous pressure shock. Failure is more likely to occur when the ceramic material has been worn off to the point where it is near the end of its use life, as determined with the feeler gauge which accompanies the KPF package. Personnel must be instructed that anytime they observe turbid water coming from the unit (not to be confused with air bubbles which may be noted upon first use of the units when new or after they have been dried out), they should check the candle for breaks or holes. When turbidity is noted personnel must not drink the product water, since high concentrations of microorganisms collected on the filter surface from previous filtrations will break free and pass through cracks or holes in the candle or through breaks in the end seals and gaskets. The high concentrations of organisms under these circumstances will significantly increase the risk of infection and illness if the water is consumed. Even post-filtration disinfection cannot be guaranteed to kill all potential pathogens which may gain access to the product water under these circumstances.

c. Silver leaching in excess of USEPA Drinking Water Criteria-- Recommend that when new or not used for a prolonged period (>48 hrs), the first quart of water produced by the KPF be voided or wasted to reduce the silver content leaching into the product water. This can be approximately measured by pumping the piston pump of the KPF at around 60 strokes/minute for 1.5 minutes. (This process will also reduce heterotrophic bacteria which may have colonized the product side of the unit; while not harmful, these bacteria and other constituents may produce an off-taste.) While the level of silver contamination found in the product water continually exceeded the USEPA lifetime consumption criteria, this is not considered to be a significant health threat to the soldier who will use the KPF for only short or intermittent periods in the field. (One gram of total accumulated silver are required to cause the disease argyria.) The USEPA's Office of Pesticide Programs for registration of pesticide-containing water treatment units does not consider the health effects of low levels of silver for other than long-term use of this type biocide.[13] Initial flushing of the first quart

of water from the unit will, however, reduce the silver content leaching into the product water and will improve aesthetic properties of the water.

d. Need for Disinfection of Product Water--It is recommended for Army personnel using the KPF that normal field canteen disinfection practices be provided for the water produced by the unit. This is necessary because viruses have not been tested and demonstrated to be adequately removed by the KPF; and, because of the 0.2 μm pore size of the KPF, it is not likely to be efficient for filtering viruses of 0.02 μm. Additionally, use of military field disinfectants will help reduce pathogen levels if the units have a partial, undetectable, or even catastrophic failure of the ceramic candle or its end seals; this will help protect the soldier from potential high levels of pathogens in the product water. Iodine tablets or calcium hypochlorite are recommended at standard field dosages and contact periods before drinking. The Marine Corps recommends that, for use of the KPF, iodine disinfection be practiced on the product water in the canteen.[3] The Command Surgeon, Army Special Operations Forces (SOF), also mandates that disinfection in accordance with FM 21-10 and FM 10-52 be practiced if Katadyn Pocket Filters are used in SOF deployments.[14]

CONCLUSIONS

1. SHORT-TERM TESTS

The results of the short-term testing of the KPF purifers using the USEPA's Guide Standard and Potocol for guidance revealed that they were not totally effective in removing the bacterial challenges provided by Klebsiella terrigena and did not consistently meet the acceptance criteria. It was also observed that the KPF units grew opportunistic Pseudomonas sp. on the product water side of the filters, which could have a significant impact on potential water quality, especially with regard to taste and odor of the water. Also, it is probable that other micro-organisms could have been growing on the product side of the filters, some of which could be opportunistic pathogens. Because of the restrictive media used for enumerating the Klebsiella, other organisms that may have been present in the product could not be detected or enumerated. It was apparent that while the silver was present in the ceramic candles to serve as a bacteriostatic agent, it was not enough to suppress the growth of the product water micro-organisms contained in the filter. On the other hand, silver leaching from the ceramic candles, while not a problem for short term or emergency requirements such as required by the military, did exceed USEPA's health criteria for lifetime consumption. The KPF filters used in the short-term testing were found to have some end-gasket seal defects which may have contributed to problems, both in allowing the challenge organisms to pass the ceramic candles into the

product water samples and in contributing to the establishment of the opportunistic bacteria regrowth on the product side of the filters. The Army prototype water filtration unit performed in a comparable manner to the KPF units until the filter clogged with worst case water. Because it could not be cleaned it had to be discarded after only 6 days into the testing program. It appeared to have no significant benefits unavailable with the KPF filters. The Army Prototype also suffered from post-filtration colonization of extraneous bacterial types.

2. LONG-TERM TESTS

The long-term tests utilized the same worst case water as was evaluated in the short-term tests where it was experimentally determined that the presence of the 30 mg/liter of test dust actually helped prolong the periods between ceramic cartridge cleaning. It was found that the major contributor to clogging was the humic acids that were provided for organic material challenge. The addition of a filter housing with a manometer to the testing program was invaluable in making sure that excessive pressures were not exerted on the ceramic candles during operations with the artificial pumping mechanism. Operating pressures were maintained at a relative constant level by reducing the pumping rate as the ceramic filter candles progressively became clogged. This helped insure that the integrity of the filters was not jeopardized during normal operation.

The second generation Katadyn ceramic filters with improved end-gasket seals performed well throughout the test; and, except for one Klebsiella sample, both test units exceeded the removal requirements of the USEPA "Guide Standard and Protocol for Testing Microbiological Water Purifiers." These filter units should be capable of safely removing typical enteric bacteria and small pathogenic protozoan cysts such as Cryptosporidium parvum, Giardia lamblia, and Entamoeba coli, from water over the effective use life of the ceramic candles. Because of the characteristics of the worst case challenge test water the units had to be cleaned frequently, which caused the ceramic material to wear away rapidly. It is likely that many source waters used in emergencies could even clog faster than observed in these tests. Therefore, it is believed that the nonorganism challenge characteristics were appropriate for the study. It would be prudent to follow the directions provided by the manufacturer regarding disassembly and drying of the units between usages, especially if these are infrequent, in order to prevent the growth of heterotrophic bacteria such as Pseudomonas sp, Flavobacterium sp, and other potentially harmful organisms inside of the units. Enteric viruses are unlikely to be removed by the KPF ceramic candles because of the large size differential between pore size (0.2 µm) of the filters and the virus dimensions (<0.05 µm). Therefore it is likely that disinfection

would have to be used to insure microbiological water safety. Disinfection could be provided in the canteen after KPF filtration, and the likely candidate is the military issue globaline tablets which are available to all field deployed soldiers.

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